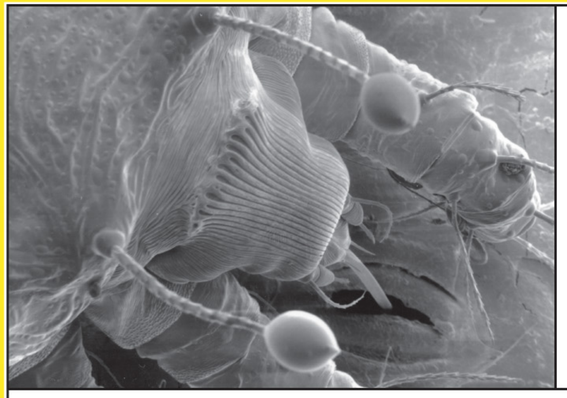

Raoiella indica Hirst (Acari: Tenuipalpidae):
An island-hopping mite pest in the Caribbean

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INTRODUCTION

In 2003, symptoms consistent with the phytoplasma-induced disease Lethal Yellowing were observed on coconut palms (*Cocos nucifera* L.) on the Caribbean island of Saint Lucia. Initial surveys conducted by Saint Lucia's Ministry of Agriculture, Forestry, & Fisheries were unsuccessful in their attempts to confirm the presence of the phytoplasma responsible for Lethal Yellowing or any other agents associated with the nutrient deficiency symptoms exhibited by the island's palms.

During continued survey work on Saint Lucia in 2004, phytophagous mites were found in association with the symptomatology. Island officials submitted mite specimens through the Insect & Mite Identification Service of the USDA-ARS Systematic Entomology Laboratory for identification. Ochoa and Kane determined the specimens to be *Raoiella indica* Hirst.

A review of the literature revealed a number of potential taxonomic issues involving this species, as well as a general paucity of detailed biological information. In response, the authors have initiated a systematic review of the genus *Raoiella*.

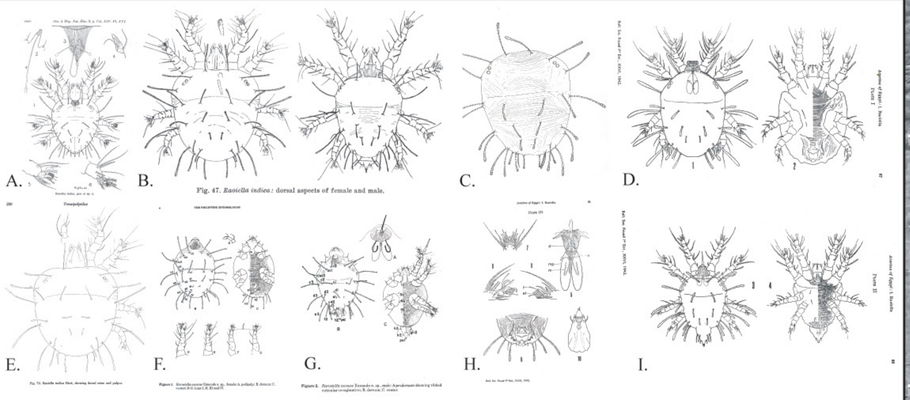

Figure 1. Illustrations of *Raoiella* species from the literature: A.) *R. indica* (Hirst 1924); B.) *R. indica* (Pritchard & Baker 1958); C.) *R. phoenica* (Smith-Meyer 1979); D.) *R. indica* (Sayed 1942); E.) *R. indica* (Jeppson *et al.* 1975); F.) *Rarosiella cocosae* (Rimando 1997); G.) *Rarosiella cocosae* (Rimando 1997); H.) *R. indica* (Sayed 1942); I.) *R. indica* (Sayed 1942)

MATERIALS & METHODS

All of the available literature dealing with the genus *Raoiella* and specifically *Raoiella indica* was reviewed. Type specimens were borrowed from the University of the Philippines Los Banos Museum of Natural History and the Natural History Museum, London, to compare with material obtained from the islands of Dominica, Martinique, and Saint Lucia.

During September 2005, Ochoa visited the island of Saint Lucia to assist officials in the Saint Lucia Ministry of Agriculture, Forestry, & Fisheries with their survey activities and to observe the mites' activity under field conditions. Live specimens of *Raoiella indica* were returned to the U.S. for examination using low-temperature electron microscopy (LTSEM) techniques at the USDA-ARS Soybean Genomics & Improvement Laboratory's Electron Microscopy Unit (EMU) in Beltsville, Maryland.

The mite specimens were prepared for imaging in the quarantine facility of the USDA-ARS Bee Research Laboratory using cryofixation techniques developed by EMU scientists. The frozen samples were then transported to the EMU and photographed on a Hitachi S4100 field emission scanning electron microscope.

RESULTS

Taxonomic Review: Preliminary studies have revealed multiple cases of potential synonomy within the genus *Raoiella*. In general, most of the existing descriptions have been based on qualitative character systems that do not adequately take into account the natural range of variation (Figure 1). In an effort to improve our understanding of this variation, quantitative data is being gathered that will provide a more objective basis for testing existing and proposed interspecific divisions.

Field Observations: Ochoa reported widespread distribution of *Raoiella indica* on Saint Lucia. Infested coconut palms were found throughout the island, from sea level to higher elevations. Population densities appeared to be highest on the lower leaves with mite colonies ranging from 20-300 individuals. Moutia (1958) reported similar figures for *Raoiella indica* infestations of coconut palms on Mauritius.

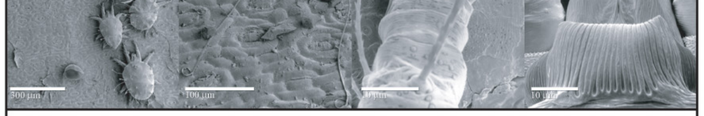

Figure 3. Low-Temperature Scanning Electron Microscopy (LTSEM) & Light Microscopy (LM) Images of *Raoiella indica* on coconut leaves:

A.) Female dorsum- (LTSEM);
B.) Female venter- (LTSEM);
C.) Female dorsum- LM;
D.) Female venter- LM;
E.) Male dorsum- (LTSEM);
F.) Male copulatory organ, note mite's ability to reflex the opisthosoma;
G.) Male dorsum- (LM);
H.) Male venter- (LM);
I-K.) Dorsal views of males engaged in pre-copulatory guarding of female deutonymphs; Progression of male opisthosomal reflection;
L.) Ventral view of coupled male and female deutonymph;
M.) Group of mites and eggs on leaf surface
N.) Egg; Note elongated "stipe"
O.) Tarsus of leg I
P.) Gnathosoma

Figure 2. *Raoiella indica* damage to coconut palms on Saint Lucia: A.) Yellowing of the lower leaves in the palm crown; B.) Differential yellowing of leaflets indicates location of mite activity; C.) Mites found on the underside of leaves in areas of discoloration; D.) Extent of mite activity indicated by the amount of white exuviae; E.) The various life stages can be identified under low magnification

Ochoa observed colonies composed primarily of eggs and immature stages (larvae, protonymphs, and deutonymphs). Of the adults that were present, males outnumbered females approximately five to one. Also, distinct coupling behavior between males and females was observed.

LTSEM Studies: The specimens examined using LTSEM have generated a number of insights into the ecology and basic biology of this species. Jeppson et al. (1975) noted the presence of a "stipe" on the eggs of *Raoiella indica*. LTSEM images of the eggs confirm the presence of this structure which potentially serves as a tether, with the distal end anchoring the egg to the leaf surface (Figure 3N).

Detailed images of the coupled specimens observed in the field indicate a pre-copulatory mate-guarding behavior (Figures 3I-L). In one image, the male clearly appears to be preparing to initiate copulation well before the female's ecdysis is complete (Figure 3K).

Mites preserved during feeding were often found in close proximity to leaf stomata, and in one instance, the stylets of a mite are clearly seen penetrating the leaf tissue through a stomata. Additionally, puncture sites in the leaves' epidermal cells are conspicuously absent.

Table 1. Known Hosts of *Raoiella* and *Rarosiella* Species

Mite	Host Plant	Family	Locality	References
Raoiella indica Hirst	*Cocos nucifera* L. (coconut)	Arecaceae	Coimbatore, South India	Hirst 1924
R indica Hirst	*Phoenix dactylifera* L.	Arecaceae	Egypt	Sayed 1942
R indica Hirst	*Areca* sp.	Arecaceae	India	Pritchard & Baker 1958
R indica Hirst	*Cocos nucifera* L.	Arecaceae	Mauritius	Moutia 1958
R indica Hirst	*Dictyosperma album* (Borg.)	Arecaceae	Mauritius	Moutia 1958
R indica Hirst	*Phoenix dactylifera* L.	Arecaceae	Mauritius	Moutia 1958
R indica Hirst	*Phoenix dactylifera* L.	Arecaceae	Sudan	Pritchard & Baker 1958
R indica Hirst	*Ocimum basilicum* L.	Lamiaceae	Pakistan	Chaudhri et al. 1974
R indica Hirst	*Phoenix dactylifera* L.	Arecaceae	Pakistan	Chaudhri et al. 1974
R indica Hirst	*Acer* sp.	Arecaceae	Russia	Mitrofanov & Strunkova 1979
R indica Hirst	*Phoenix dactylifera* L.	Arecaceae	Israel	Gerson et al. 1983
R indica Hirst	*Areca catechu* L.	Arecaceae	India	Nageshachandra & Channabasavanna 1984
R indica Hirst	*Cocos nucifera* L.	Arecaceae	India	Nageshachandra & Channabasavanna 1984
R indica Hirst	*Phaseolus* sp.	Fabaceae	India	Gupta 1984
R indica Hirst	*Phoenix dactylifera* L.	Arecaceae	United Arab Emirates	Gassouma 2003
R indica Hirst	*Cocos nucifera* L.	Arecaceae	La Reunion Island	Ueckermann 2004
R indica Hirst	*Cocos nucifera* L.	Arecaceae	Martinique, West Indies	Flechtmann & Etienne 2004
R indica Hirst	*Veitchia merrillii* (Becc.)	Arecaceae	Martinique, West Indies	Flechtmann & Etienne 2004
R indica Hirst	*Phoenix dactylifera* L.	Arecaceae	Saudi Arabia	Alhudaib 2005
R indica Hirst	*Aiphanes* sp. (Multiple crown palm)	Arecaceae	Saint Lucia, West Indies	Kane et al. (in prep.)
R indica Hirst	*Cocos nucifera* L.	Arecaceae	Pattaya & Bangkok, Thailand	Kane et al. (in prep.)
R indica Hirst	*Cocos nucifera* L.	Arecaceae	Saint Lucia and Dominica, West Indies	Kane et al. (in prep.)
R indica Hirst	*Dypsis lutescens* (H.Wendl.)	Arecaceae	Saint Lucia, West Indies	Kane et al. (in prep.)
R indica Hirst	*Musa acuminata* Colla	Musaceae	Saint Lucia and Dominica, West Indies	Kane et al. (in prep.)
R indica Hirst	*Musa balbisiana* Colla	Musaceae	Saint Lucia and Dominica, West Indies	Kane et al. (in prep.)
R indica Hirst	*Musa uranoscopus* Lour.	Musaceae	Saint Lucia, West Indies	Kane et al. (in prep.)
R indica Hirst	*Musa x paradisiaca* L.	Musaceae	Saint Lucia and Dominica, West Indies	Kane et al. (in prep.)
R indica Hirst	*Syagrus ramanzoffianum* Glassman (Queen palm)	Arecaceae	Saint Lucia, West Indies	Kane et al (in prep.)
R indica Hirst	*Veitchia merrillii* (Becc.)	Arecaceae	Saint Lucia, West Indies	Kane et al. (in prep.)
Raoiella phoenica Meyer	*Phoenix dactylifera* L.	Arecaceae	Nuri, Sudan	Meyer (Smith) 1979
Rarosiella ccosae Rimando	*Cocos nucifera* L.	Arecaceae	Camiguin Island, Philippines	Rimando 1996

DISCUSSION

LTSEM studies have proven useful in enhancing our understanding of the morphology, biology, and ecology of *Raoiella indica* Hirst. Eveidence from LTSEM studies and field observations suggests that female adults most likely play a major role as the dispersal stage for this species. Insemination appears to occur during the female's final ecdysis, thus preparing her for immediate dispersal by ensuring her ability to initiate a new colony. Low numbers of females in high-density colonies, and the discovery of isolated females surrounded by clusters of 20-30 eggs both support this hypothesis.

The symptomatology exhibited by infested plants is indicative of nutrient deficiency. This could be explained by the observation that the mites appear to be feeding on the nutrient-rich layers of the leaves' mesophyll tissues. The resulting "yellowing" is distinctly different from the "silvering" that often results from feeding on epidermal cells.

The discovery of *Raoiella indica* on Saint Lucia, along with confirmed reports over the past two years of this species on the nearby islands of Dominica and Martinique represent the first documented records of this species in the Western Hemisphere. While this species has been reported from over a dozen host plants (Table 1), it is predominantly associated with palms. However, recent reports of high populations found on commercial banana plants on the island of Dominica should raise additional concerns about its potential economic impact (Naomi Commodore, Dominica, pers. comm.).

Given the widespread damage observed on Saint Lucia associated with this mite; its documented host diversity; and its demonstrated ability to shift hosts, the potential clearly exists for further expansion of the species' range throughout the Caribbean region, as well as the tropical and subtropical portions of North, Central, and South America.

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